Nanotechnology: Giga game for soils

Siddhartha S. Mukhopadhyay

Electron Microscopy and Nanoscience Laboratory,
Punjab Agricultural University,
Ludhiana – 141004, India

[e-mail <siddhartha_soil@yahoo.co.in>,
<ssmukho@pau.edu>]

What is NT?

- **understanding and control of matter at dimensions of roughly 1-100 nm, where unique physical properties make novel applications possible**

(*EPA, 2007*)

- **is a new interdisciplinary venture-field that converge science, engineering, and agriculture and food systems into one**

  – Dr. APJ Abdul-Kalam

- ***original meaning:***

  designing and building machines in which every atom and chemical bond is specified precisely

  (Hall, 2006; p.21)

Opportunity

- **touted as a second industrial revolution**

  (*Introduction by Drexler in Hall, 2006*).

Public acceptance of NT

Risks and benefits analysis showed

NT is neutral, and better placed than GMO, Stem cell, Biotech, Nuclear Power etc.

Currallet al. (2006) Nature Nanotechnology

Background

“like solid-state physics in the sense that it might tell us much of great interest about the strange phenomena that occur in complex situations” that “would have an enormous number of technical applications” and involved “the problem of manipulating and controlling things on a small scale”.

- Richard Feynman, 1959

(There's plenty of room at the bottom)

The game people play: Is clay science a winner in NT game?

NT is like a game of Quiddich that Harry Potter and other pupils played in the School of Magic.
No matter what's the score, if the seeker catches snitch, his team wins.

Clay science is not a winner,

but a conqueror

But, what is the scientific basis of the statement: Clay science is not a winner, but a conqueror?

Origin of NS

The origins of nanoscience can be traced

to clay mineralogy and crystallography

when it was discovered that clay minerals were crystalline and of micrometer size

(Lower et al., 2001)

Advantages of clays

- The ever-growing application of clays in nanotechnology rests on fundamental principles of colloid chemistry
- They make soils as nature's great electrostatic chemical reactor
- The unit cell dimensions of clay minerals are in nanometer scale in all three axes

- ordered arrangements,
- large adsorption capacity,
- shielding against sunlight (UV rad),
- ability to concentrate organic chemicals, and
- ability to serve as polymerization templates

Some successful ventures of nanotechnology in agriculture

Product	Application	Institution*
Nanocides	**pesticides encapsulated in nanoparticles for controlled release**	BASF
	nanoemulsions for greater efficiency	Syngenta
Bucky ball fertilizer	**ammonia from buckyballs**	Kyoto Univ, Japan
Nanoparticles	**Adhesion-specific nanoparticles for removal of *Campylobacter jejuni* from poultry**	Clemson Univ.
Food packaging	**airtight plastic packaging with silicate nanoparticles**	Bayer
Use of agri-cultural waste	**nanofibres from cotton waste for improved strength of clothing**	Cornell univ
Nano-sensors	**contamination of packaged food**	Nestle, Kraft
	pathogen detection	Cornell Univ
Precision agriculture	**nanosensors linked to GPS for real-time monitoring of soil conditions and crop growth**	USDA
Live stock and fisheries	**nano-veterinary medicine (nanoparticles, buckyballs, dendrimers, nanocapsules for drug delivery, nanovaccines; smart herds, cleaning fish ponds (Nanocheck); feed (iron nanoparticles)**	Cornell Univ, Nanovic,

What will nano materials do to the environment?

NP in electronics, biomedical, ceramics, pharmaceutical, cosmetic, energy, environmental, catalytic, material etc. has alarmed concern for environmental safety

Year	Amount of Engineered material used
2004	2000 tons
2011-2020	58000 tons (expected)

Zeophonics

- System founded on the concept of interconnected nature of all life-forms and life-support-forms
- Relies on recycling and operation of system-components
- The system provides a framework where impetus and response are almost equal.

Possible innovations

- nano-enhanced products (e.g. nanofertilizers and nanopesticides)
- nano-based smart delivery system (use of halloysite)
- Nanoporous materials (e.g. hydrogels and zeolites)
- Nanomaterials (sorbents of pollutants)

(Lal, 2009)

Nanotechnology and clay

Ionic character (%) of a bond is determined by the difference between the electronegativities of the two atoms concern, and can be expressed by using Pauling's equation:

$$p = 16|x_A - x_B| + 3.5\,|x_A - x_B|^2$$

Si-O bond ~ 33.8% ionic,

Al-O bond ~ 46.0% ionic

Manipulation of bonds

- **Si replaced by Al - increase of 12.2%**

  ionic character in silicon tetrahedron
- **If Si is replaced by Al in zeolite framework structure, the tunnel diameter changes**
- **Organic materials can bridge different**

Why is clay based NT a distinct field?

- Depart from traditional NT (e.g., nanoelectronics, nanomaterials)
- Depart from conventional appl. fields (e.g., cell phone, computer, sensors)
- Clay – an interface of physical and biological worlds
- Soil is the central domain of GBAH-spheres

Nanofrabication with clay: Methods

- Methods followed in industry (like melting materials at a high temp. to segregate atoms / ions at plasma state) cannot be copied
- Stability of mineral in soil environment is important

Is that a hindrance?

No, because
system obeys the laws of ion exchange, adsorption-desorption, aggregation - dispersion, solubility-dissolution etc.
Most vital yardstick is
that the system has to be capable of releasing nutrient ions in plant-available forms
"Clay-Plant nutrient nanofactory"

Control of clay based NT

- **does not promise a control system that we experience in electrical machines, or in satellites, or in chemical reactors.**

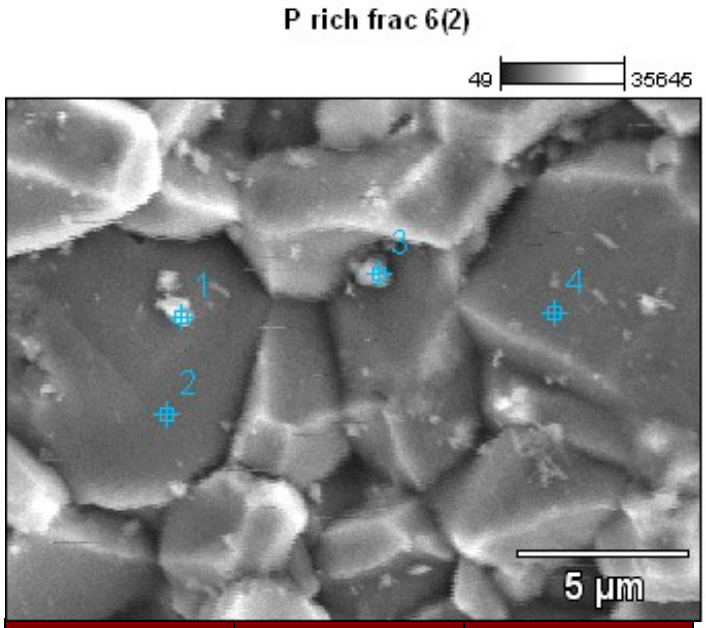
It has to be knowledge based passive system

Promise Clay-NT makes

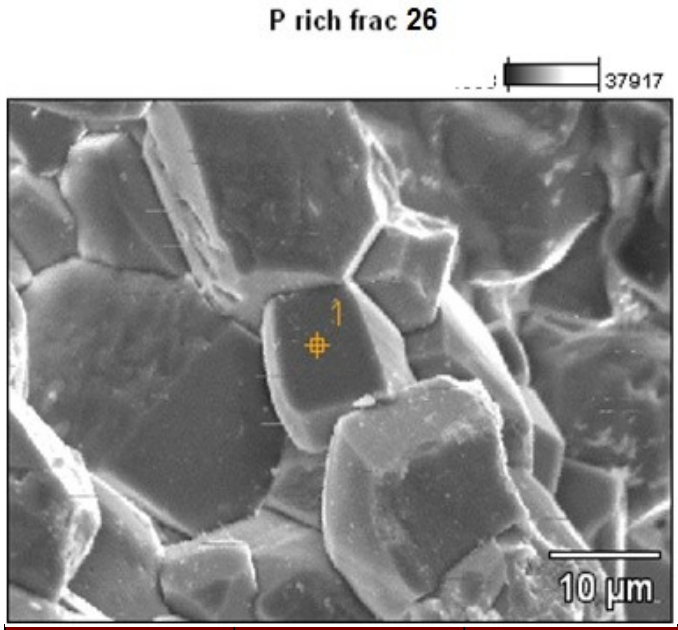
- **going to create millions of rhizospheres in an acre of land to support the growth of millions of plants of a crop;**

a breakthrough to place agriculture into new millennium

P-rich minerals do not contain heavy metals: SEM-EDS evidence



Element	Weight %	Atom %
C	7.69	15.72
O	25.09	38.51
F	1.89	2.45
P	18.26	14.48
Ca	47.06	28.84
Total	100.00	100.00



Element	Weight %	Atom %
C	5.94	12.76
O	23.95	38.59
P	18.92	15.74
Ca	51.19	32.92
Total	100.00	100.00

Domain of uncertainty

- **Positional uncertainty**
- **Command structure**
- **Transport uncertainty (e.g., preferential flow; groundwater contamination)**
- **Self regulatory behavior**
- **Surface energy**

Nanotechnology in agriculture is a castle in the air

Nanotechnology in agriculture is a castle in the air

Just put foundation beneath it

Thank you